Fabrication of Single Electron Transistor using SWNT

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The single electron transistor (SET) is a device in which a quantum dot (QD) is connected with source and drain contacts through small tunnel junctions. It also has a gate electrode through the "classical" capacitor that does not allow any tunneling of electrons. The operation of the SET is well characterized by the so-called Coulomb diamond and the Coulomb oscillations. Here we make use of Single Walled Carbon Nanotubes as a QD. One of the unique features of SWNT QDs is that the SET operates at relatively high temperatures, compared with semiconductor QDs with a submicron size. This is simply because the SWCNT QD is small. Our aim is to find novel techniques for fabricating nanodevices reproducibly and efficiently. One of the techniques to make such a device is to radiate the metal-like SWNT in controlled regions with low powered electron beam to convert a portion of it to semiconductor-like SWNT to create an intervening QD. Another technique involves chemically assembling the carbon nanotubes on to a gold template by exploiting the strong non-covalent interaction between biomolecules Biotin and Streptavidin.

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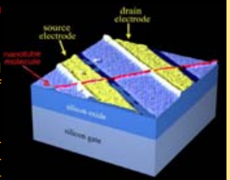
Introduction

Using molecules as electronic components is a powerful new direction in the science and technology of nanometer-scale systems. Molecular electronics could lead to conceptually new miniaturization strategies in the electronics and computer industry. On such scales, quantum phenomenon largely comes to dominate the characteristics and function of such devices. Single electron transistors (SETs) have been proposed as a future alternative to conventional silicon electronic components. Single-electron transistor is a device that exploits the quantum effect of tunneling to control and measure the movement of single electrons However, most SETs operate at cryogenic temperatures, which strongly limits their practical applications. We have exploited the use of individual metallic single walled carbon nanotube (SWNT) molecules to fabricate SETs.

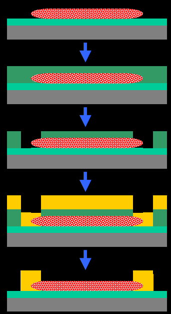
Advantages of using Single Walled Carbon Nanotubes for SETs:

SETs need to be fabricated in nanoscale, which is difficult to realize with conventional lithography, so we have explored the use of carbon nanotubes as building blocks.

SETs need to operable at room temperature; SWNT QDs compared with semiconductor QDs with a submicron size, are a lot smaller and can thus operate at a higher temperature.



Procedure to Fabricate Single Electron Transistors



Spincoat nanotubes onto Si/Sio_2 substrate

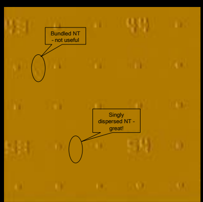
Coat with photoresist

Use E-beam lithography to design electrodes and etch the exposed resist

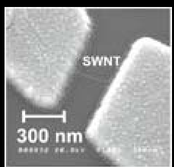
Evaporate a thin film of Ti metal

Lift-off remaining resist and device is ready!

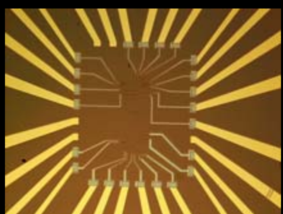
Microscopy Data



AFM image of the SWNT spincoated on the substrate



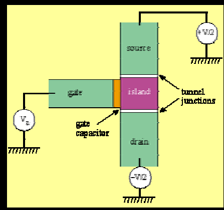
Fabricating Electrodes across singly dispersed SWNT



AFM image of the ten SETs on a Si/Sio_2 substrate

Operation of a Single Electron Transistor

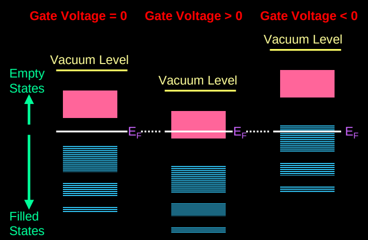
The single-electron tunneling (SET) transistor consists of a gate electrode that electrostatically influences electrons traveling between the source and drain electrodes. The electrons in the SET transistor need to cross two tunnel junctions that form an isolated conducting electrode called the island. Electrons passing through the island charge and discharge it.



When V_{DS} is applied between the source and drain, system is driven out of equilibrium; the Fermi energies in the source and drain will not be at the same level any more.

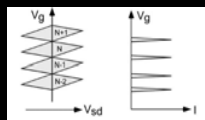
Total energy difference between the two Fermi levels (chemical potentials) μ_1 and μ_2 is qV_D.

Fermi energy (or electrochemical potential) is held fixed by source and drain reservoirs and only a gate bias is applied. Based on the sign of this voltage the energy levels of the island move up or down.



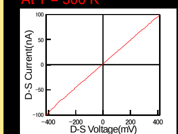
As the gate bias is applied, peaks in current or Coulomb oscillations are observed.

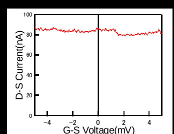
The Coulomb diamonds of conductance are obtained as a result of superposition of the Coulomb gap in V_{SD} and the Coulomb oscillations in V_G.



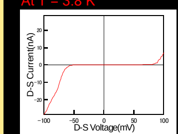
Electrical Measurements on SWNT SETs

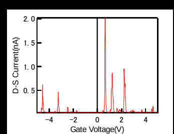
At T = 300 K

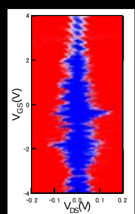




At T = 3.8 K





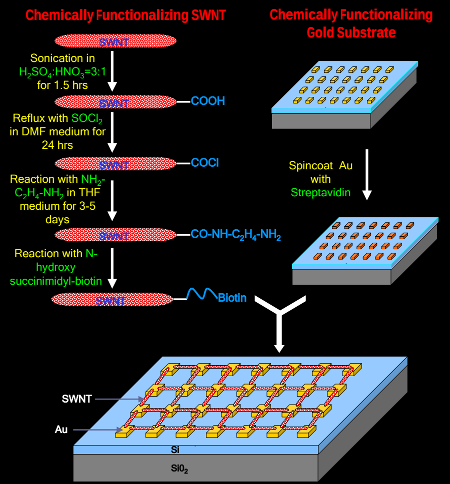


The Coulomb Diamond of the SET below shows Multi-dot phenomenon possibly due to defects in the nanotube structure.

Biomolecular Self Assembly of SWNT

The interaction between biotin, a component of vitamin B complex and streptavidin, a small bacterial protein, is one of the strongest biomolecular interactions known. The avidin is a tetramer and so has four sites to bind biotin molecules.

The high stability of the biotin-avidin interaction can be used to assist in the assembly of nanoscale supramolecular architectures. Biotin-functionalized nanotubes can link specifically to surface regions that have been modified with avidin. Thus enabling biomolecularly-assisted assembly of nanotubes onto a surface.



Now make electrical contact on this predefined template of the nanotube matrix above to obtain a grid of Single Electron Transistors on a scale of a few microns as opposed to the conventional chips having size scale of thousands of microns.

Conclusion & Future Work

Here we seek to make a quantum integrated chip of single electron transistors, from chemically assembled nanotube matrix. By functionalizing the nanotube end caps and the surface, we can control the position of the nanotube molecule. By harnessing the specific interaction between the biotin and streptavidin biomolecules, we can construct electronic devices on a scale where the quantum phenomenon such as single electron charging and energy level quantization dominate. The ability to design such nanoscale architectures will be important in molecular electronics and in the study of the physics of nanometer-scale systems.

References

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Acknowledgements

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